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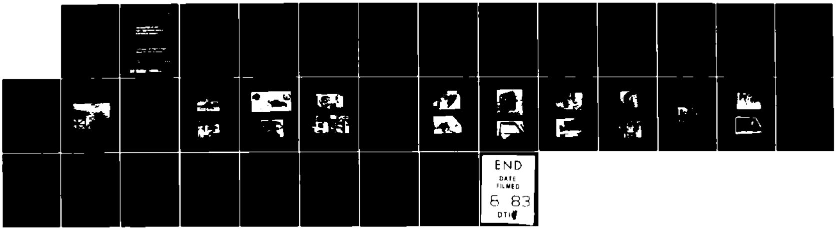

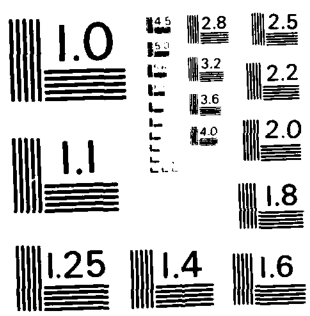

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CAPABILITIES OF THE NRCC/NAE FLIGHT IMPACT SIMULATOR FACILITY

CAPACITÉ DU SIMULATEUR D'IMPACT EN VOL DU CNRC/ÉAN

by/par

J.B.R. Heath, R.W. Gould and G.R. Cowper

National Aeronautical Establishment

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Director/Directeur

SUMMARY

This report describes the NRCC/NAE Flight Impact Facility in which birdstrike tests on aircraft parts can be carried out. Technical information is given on the capabilities of the pneumatic cannon used to fire real bird carcasses against stationary targets, and on the auxiliary apparatus and instrumentation available at the Facility.

SOMMAIRE

Ce rapport décrit le Simulateur d'impact en vol du CNRC/ÉAN destiné aux essais d'impacts d'oiseaux contre les composantes d'avions. On présente des renseignements techniques sur le canon pneumatique qui sert à lancer des carcasses d'oiseaux contre des cibles fixes, ainsi que des renseignements sur les appareils auxiliaires et les instruments de mesure disponibles sur place.

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ILLUSTRATIONS

ILLUSTRATIONS (Cont'd)

CAPABILITIES OF THE NRCC/NAE FLIGHT IMPACT SIMULATOR FACILITY

1.0 INTRODUCTION

Research and development in the field of bird impact resistance of aircraft has been and remains a significant activity within the National Aeronautical Establishment (NAE), a division of the National Research Council Canada (NRCC). In 1968 at the request of Canadian Industry the NAE set up a Flight Impact Simulator Facility in which bird strikes on aircraft components can be simulated and the resulting structural damage can be studied under laboratory conditions. The principal tool of the Facility is a pneumatic cannon which can propel bird carcasses against stationary targets at speeds up to 390 m/sec.

Since publication of the report "Capabilities of the NAE/NRC Flight Impact Simulator Facility" in 1974, many improvements have been implemented. Upper and lower velocity limits have been extended, environmental conditioning equipment and procedures have been improved, high speed filming techniques have been refined, and instrumentation has been updated.

It is the purpose of this report to provide information on the present capabilities of the Facility.

2.0 THE FACILITY

2.1 The Site

The Facility is located on the NRCC/NAE grounds adjacent to Ottawa International Airport. The Facility is housed in a building consisting of two areas, one that contains the pneumatic cannon and support equipment, and a test area in which the specimens are located. A plan view of the test area is shown in Figure 1. Located approximately 45 meters from the end of the building is a semi-circular embankment with a perimeter fence that secures the area. Along the line-of-fire, set into the embankment, is a 2.4 $\times$ 2.4 $\times$ 2.4 meter wooden crib to arrest bird packages during calibration shots.

2.2 The Pneumatic Cannon

The cannon is shown in Figure 2 and schematically in Figure 3. It consists of a 1.70 m^3 reservoir (working pressure 1380 kilopascals), a 0.03 m^3 step chamber, Figure 4, and a 12.2 m long by 25.4 cm bore barrel. At the barrel muzzle is a spring-mounted sabot arrestor (Fig. 5).

The cannon support frame can be pivoted at the reservoir end for aiming. The frame can also be raised or lowered to facilitate testing of various size specimens. The impact point can vary from one to three meters above the target area floor.

The cannon utilizes a double diaphragm system for pressurizing and firing. The reservoir and step-chamber are pressurized simultaneously in the ratio of 2:1, to the predetermined test pressure, each of the two diaphragms supporting one-half of the reservoir pressure. Diaphragms of various burst pressures are selected so that they will support one-half reservoir pressure but will burst at full pressure.

The cannon is fired by energizing two large-port solenoid valves, quickly releasing the step-chamber pressure. Full reservoir pressure now successively ruptures the two diaphragms and the energy of the compressed air accelerates a sabot containing the bird package down the barrel. The sabot is retained by the sabot arrestor and the bird package continues to the impact point.

2.3 Sabot

International air-worthiness codes have established 0.9, 1.8, and 3.6 kg birds as standard weights for impact testing.

Because of the large barrel diameter, various package weights (0.45 to 4.5 kg) can be used at the Facility. A sabot is required to contain the bird packages, but it is also vital for supporting the birds during acceleration.

Sabots of various metal alloys and thickness, with a filler material of aluminum honeycomb or polyurethane foam, have been developed. Different container-filler combinations are used depending on the required bird package size and velocity.

At present the sabot — sabot arrestor system can be used successfully for a 1.8 kg bird at velocities up to 400 m/sec. Figure 6 shows the sabot components, bird package, and sabot with bird package ready for firing. Figure 7 shows examples of spent sabots.

2.4 Birds and Packaging

All bird impact testing at the facility is carried out with domestic chickens. The birds are selected by weight, asphyxiated, packaged in air-tight polyethylene bags and frozen for storage.

Prior to use the birds are thawed at room temperature for at least 24 hours (0.9 and 1.8 kg birds) or 48 hours (3.6 kg birds).

The bird weight and final bird package weight is recorded, just prior to use.

Packaging of the bird varies with the required velocity. Low velocities require only that the polyethylene storage bag be wrapped with a number of turns of masking tape. At extremely high velocities heavy nylon bags are required to prevent the bird from disintegrating during initial acceleration.

For approximately 90% of the impacts carried out at the Facility, the bird in the polyethylene is packaged in a light cotton bag. This packaging is used for velocities up to 215 m/sec.

2.5 Diaphragms

The diaphragms used in the cannon are cut from Mylar (polyester) film in thicknessess ranging from 0.025 to 0.25 mm. The consistent bursting pressure exhibited by this material is an important factor in maintaining the predictability and reliability of the velocity imparted to a bird package.

An in-house study of the bursting characteristics of the Mylar diaphragms indicated that variables such as pressure rise rate, stacking of diaphragms, creep under load, artificial heat aging, and creasing did not significantly affect the burst pressure. It was found, however, that the burst pressure of diaphragms of the same thickness but of different lot or mill run could vary by as much as 35%. Consequently, burst testing is carried out on each new lot of film received.

2.6 Specimen Set-Up and Targetting

Typical test set-ups are shown in Figure 8, while Figure 9 is a drawing of the primary supporting structure available at the Facility.

A helium-neon laser is used for positioning the test specimen so that the proper impact point is obtained. The laser is placed in the muzzle of the cannon such that the laser beam is aligned with the axis of the gun barrel. The specimen is then moved until the impact point coincides with the laser beam. The beam is also used as a reference to set the longitudinal axis of the test article. Sweep-back angles are set to within $\pm\frac{1}{2}^\circ$ with an apparatus employing the laser beam as a reference. The apparatus is shown being used in Figure 10. Pitch and roll angles are set by means of a clinometer to within $\pm\frac{1}{2}^\circ$.

2.7 Environmental Conditioning

The temperature of a transparency is an important parameter in bird impact testing. Typical temperature requirements range from a low of $-40^\circ C$ to a high of $50^\circ C$ and soak times can be as long as one or two hours depending on specimen thickness. The Facility has a number of methods of carrying out temperature conditioning.

If a complete front fuselage section containing the test transparency must be conditioned, a chamber can be set up to enclose the complete fuselage section. The chamber can be erected to a maximum size of 3.7 m by 4.9 m by 3 m high. The erected environmental chamber is shown in Figure 11.

Most of the impact testing, however, can be carried out by heating or cooling only the transparency. For these tests an insulated enclosure, with cover, is fitted around the specimen. Conditioned air is then ducted into the enclosure until temperature requirements are met. A few seconds before firing the cannon the cover is removed remotely so as not to interfere with the impact. Figure 12 shows a typical enclosure with the cover removed.

Both enclosures are suitable for either high or low temperature tests.

For the low temperature testing air mixed with liquid nitrogen in a mixing box, shown in Figure 13, is ducted into the enclosure. Heated air from an oil-fired unit heater is ducted directly to the enclosure for the high temperature work.

Two other methods can be used for the high temperature tests. One utilizes the heat generated from the high intensity lights required for motion picture photography. A second procedure is to apply heat to the test specimen with a flexible heating blanket. The outer face of the blanket is covered with insulation and the temperature is controlled by varying the applied voltage. The insulating cover and blanket are removed prior to impact. The set-up, during heating, is shown in Figure 14.

2.8 Instrumentation

2.8.1 Velocity Measurement

The velocity of the bird package prior to impact is the single most important parameter to be measured in any impact test.

The Facility utilizes a timing frame (Fig. 15) with optoelectronic timing systems that measure the time interval for a bird package to traverse the known distance, (nominally 0.8 m) between a pair of light beams. Redundancy is provided by three independent systems mounted horizontally, diagonally, and vertically (Fig. 16), all perpendicular to the line of fire.

The recorded test velocity is the mean obtained from the three systems.

Calibration of the timing systems is carried out regularly. An apparatus with a tube representing a bird package is positioned centrally along the horizontal axis of the timing systems. The tube is moved slowly through the light beam of a particular system to the point where triggering of a timer-counter will not occur by interruption of the whole light beam. The tube is then moved in the opposite direction until triggering can now occur by beam interruption. This "go no-go" band is approximately 0.13 mm wide and is taken as the trigger point for the particular timing unit. The procedure is repeated for the remainder of the "start" and "stop" units and the interval distances are read from a scale attached to the apparatus to an accuracy of ±0.25 mm. The apparatus, in position, is shown in Figure 17.

2.8.2 Bird Weight

The weight of the bird and complete bird package is measured just prior to use on an electronic scale with a resolution of ±1 g. The scale is checked periodically with a set of calibrated weights.

2.8.3 High Speed Film Coverage

The facility has two 16 mm Hycam cameras capable of filming at the rate of 10 000 frames per second. A quarter-frame prism is also available which can produce 40 000 quarter-frame pictures per second. An additional two Fastex 16 mm cameras are also on hand.

A photo-optical data analyzer is used for viewing the high speed films in the Facility's projection room. Normally the negative is available the day following the impact test.

Lighting for filming is supplied by banks of high intensity aircraft landing lights and long-duration high-intensity flash bulbs. The latter are used for confined spaces.

2.8.4 Still Photographs

The Facility is well equipped with cameras for still photography. Both 35 mm and Polaroid cameras are used.

The Facility also has a light table for back lighting of damaged transparencies. As can be seen in Figure 18, use of the table highlights the fracture surfaces of a damaged specimen.

2.8.5 Temperature Measurement

Grid-type copper-constantan thermocouples at various points on a transparency are used to monitor the temperature. In most cases two thermocouples are employed, one on the outside surface at the impact point and one on the inside surface of a transparency. These are monitored simultaneously on digital indicators and strip-chart recorders, so that an instantaneous reading at impact and a temperature-time history can be obtained. At present a total of four thermocouple channels are normally available. However, a data logger for monitoring additional thermocouples can be made available if required.

2.8.6 Strain Measurement

Recently, impact tests have been carried out requiring strain measurements of windwhield panels. The Facility is experienced in the recording, analyzing and processing of such data.

In another recent test, measurements were made of the peak force and force-time history on a leading edge section during an eight-pound bird impact. A steel plate (152.4 cm long by 30.48 cm wide, by 2.54 cm thick) backed by two 22,700 kg load cells, was designed for the tests. A schematic of the test set-up is shown in Figure 19. The data was collected on a digital oscilloscope and magnetic tape recorder, and processed by a graphic system with a hard copy output.

2.8.7 Ballistic Pendulum

The Facility has ballistic pendulums which may be used to measure impulses and momentum transfer during bird impacts. A program to study momentum transfer during bird impacts has been carried out at the Facility and is reported in Reference 1, which also contains a full description of the pendulums. The pendulums are currently being used in an R & D program to develop a bird-resistant composite leading edge for airfoils. A schematic of a typical test set-up is shown in Figure 20. If penetration of the test specimen occurs the ballistic pendulum mounted behind the specimen measures the residual momentum of the bird debris. The ratio of residual momentum to initial bird package momentum is a useful measure of the relative performance of different leading edge designs.

3.0 PERFORMANCE

The majority of testing carried out at the Facility utilizes a 1.8 kg bird package, with velocities ranging from 90 to 300 m/sec.

Figure 21 shows the general pressure versus velocity relation for this range. The graph shown in Figure 21 is a mean curve based on the results of several hundred firings of the gun. The actual velocity attained in any one shot will vary somewhat from the mean curve because of normal and uncontrollable variations in ambient conditions, in sabot weights and other factors. The extent of the variation is shown in Figures 22, 23 and 24 in which are plotted the individual data points on which the curve of Figure 21 is based. The extreme variation from the mean curve is of the order of ±8 m/sec throughout the complete velocity range. On average, however, the departure from the mean curve is much smaller than this. For example, at a pressure setting of 60 kPa the mean velocity is 76.2 m/sec and the standard deviation of the observed velocities is 2.1 m/sec. At a pressure setting of 250 kPa the mean velocity is 185 m/sec and the standard deviation is 1.5 m/sec.

Velocities below 61 m/sec are achieved by the use of a throttle plate at the reservoir outlet and by inserting the sabot at various distances (normally 3 m) from the muzzle.

The maximum attainable velocity is limited by the allowable working pressure of the reservoir. Under normal operating conditions the maximum velocity of a 1.8 kg bird package is about 330 m/sec. This can be increased to 390 m/sec by the installation of a mylar diaphragm at the muzzle and evacuation of the barrel prior to firing. The maximum velocity can be further increased by using helium, instead of air, as the driving gas. With helium, a 0.9 kg bird package has been successfully fired at a velocity of 465 m/sec using a reservoir pressure of 690 kPa. This pressure is only one-half of the maximum allowable reservoir pressure. Obviously the maximum velocity of a 1.8 kg package could be increased substantially with helium as the driving gas, but containing the sabot at these speeds requires further development work.

The curves of pressure versus mean velocity for 0.9 kg and 3.6 kg bird packages are shown in Figures 25 and 26 respectively. The gun is fully calibrated for the following bird package weights and velocity ranges:

0.45 kg bird from 37 to 213 m/sec
0.90 kg bird from 15 to 213 m/sec
1.80 kg bird from 30 to 387 m/sec
3.60 kg bird from 76 to 229 m/sec

4.0 UTILIZATION OF THE FACILITY

The Facility has been in continuous operation since its inception in 1968. Over 2000 shots have been fired.

Several in-house research projects have been carried out at the Facility. These include a study of single-ply windshields of the type used in light aircraft (Refs. 2, 3), an investigation of the effect of aging on the impact resistance of polycarbonate (Ref. 5), and measurements of momentum transfer in bird impacts on flat plates (Ref. 1). An investigation of the bird impact resistance of various designs of leading edges is near completion.

In addition to in-house research projects, numerous bird impact tests have been carried out for the following external organizations:

Canadair Ltd.
De Havilland Aircraft of Canada Ltd.
Department of National Defence, Canada
PPG Industries Inc.
McDonnell Douglas Aircraft Corp.
Fairchild Republic Co.
Federal Express Ltd.
Sierracin Sylmar Corp.

Certification of aircraft components for compliance with Transport Canada and FAA standards of bird impact resistance has been an important part of the work of the Facility. Looking to the future, one can foresee a continuing need for bird impact investigation as new materials and new light-weight designs are introduced.

5.0 REFERENCES

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2. Heath, J.B.R., Bosik, A.J. — *Bird Impact Test Program for Windshields of Small Light Aircraft.* Conference on Aerospace Transparent Materials and Enclosures, Atlanta, Ga., November 1975, AFML-TR-76-54, pp. 854-885.

3. Bosik, A.J., Heath, J.B.R. — *A Study of Bird Impacts on Monolithic Aircraft Windshields.* NRCC/NAE Laboratory Technical Report LTR-ST-998, April 1978.

4. Bosik, A.J., Heath, J.B.R. — *Ballistic Tests on Simulated Aircraft Cabin Windows.* NRCC/NAE Laboratory Technical Report LTR-ST-1043, December 1978.

5. Heath, J.B.R., Gould, R.W. — *Degradation of the Bird Impact Resistance of Polycarbonate.* NRCC/NAE Laboratory Technical Report LTR-ST-1326, January 1982.

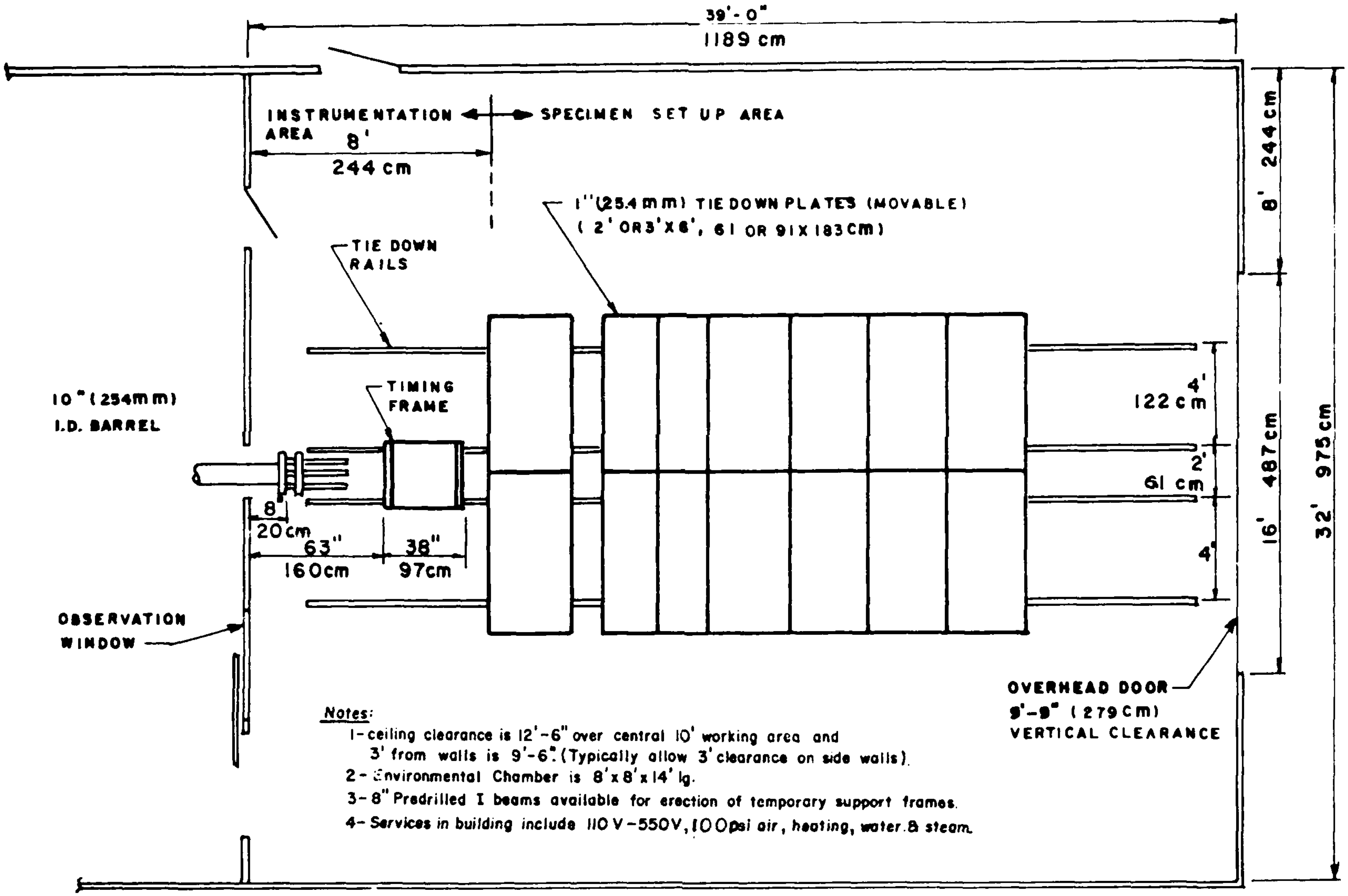


FIG. 1: PLANVIEW OF NAE FLIGHT IMPACT SIMULATOR TEST AREA

FIG. 2: OVERALL VIEW OF CANNON

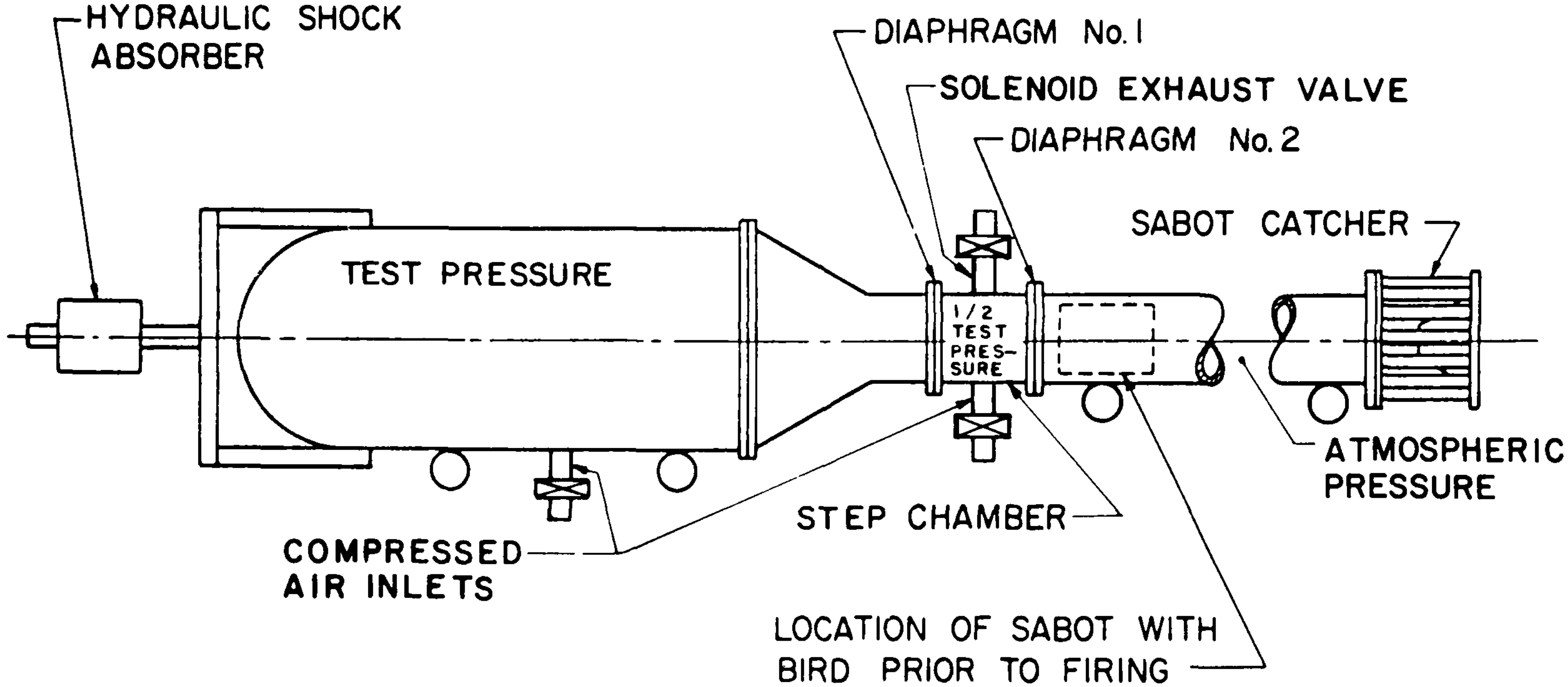


FIG. 3: DIAGRAM OF PNEUMATIC CANNON

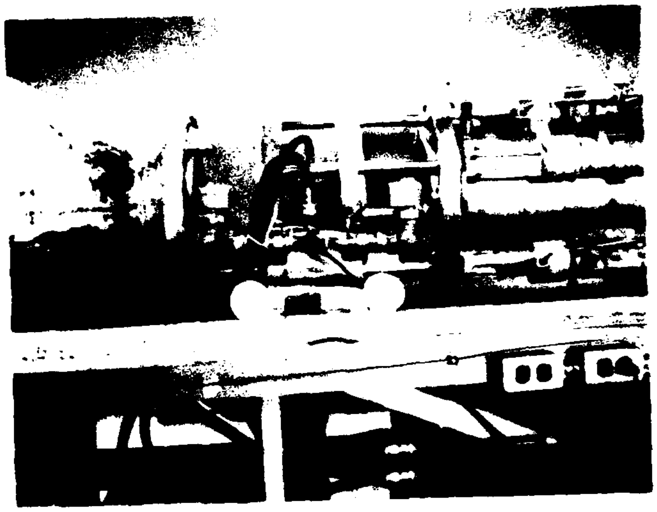


FIG. 4: STEP CHAMBER

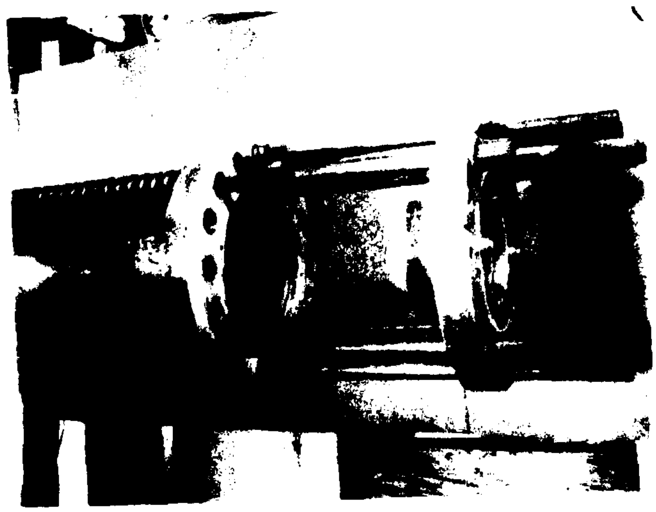


FIG. 5: SABOT ARRESTOR

FIG. 6: SABOT COMPONENTS. BIRD PACKAGE AND ASSEMBLED SABOT WITH BIRD PACKAGE READY FOR FIRING

FIG. 7: EXAMPLES OF SPENT SABOTS

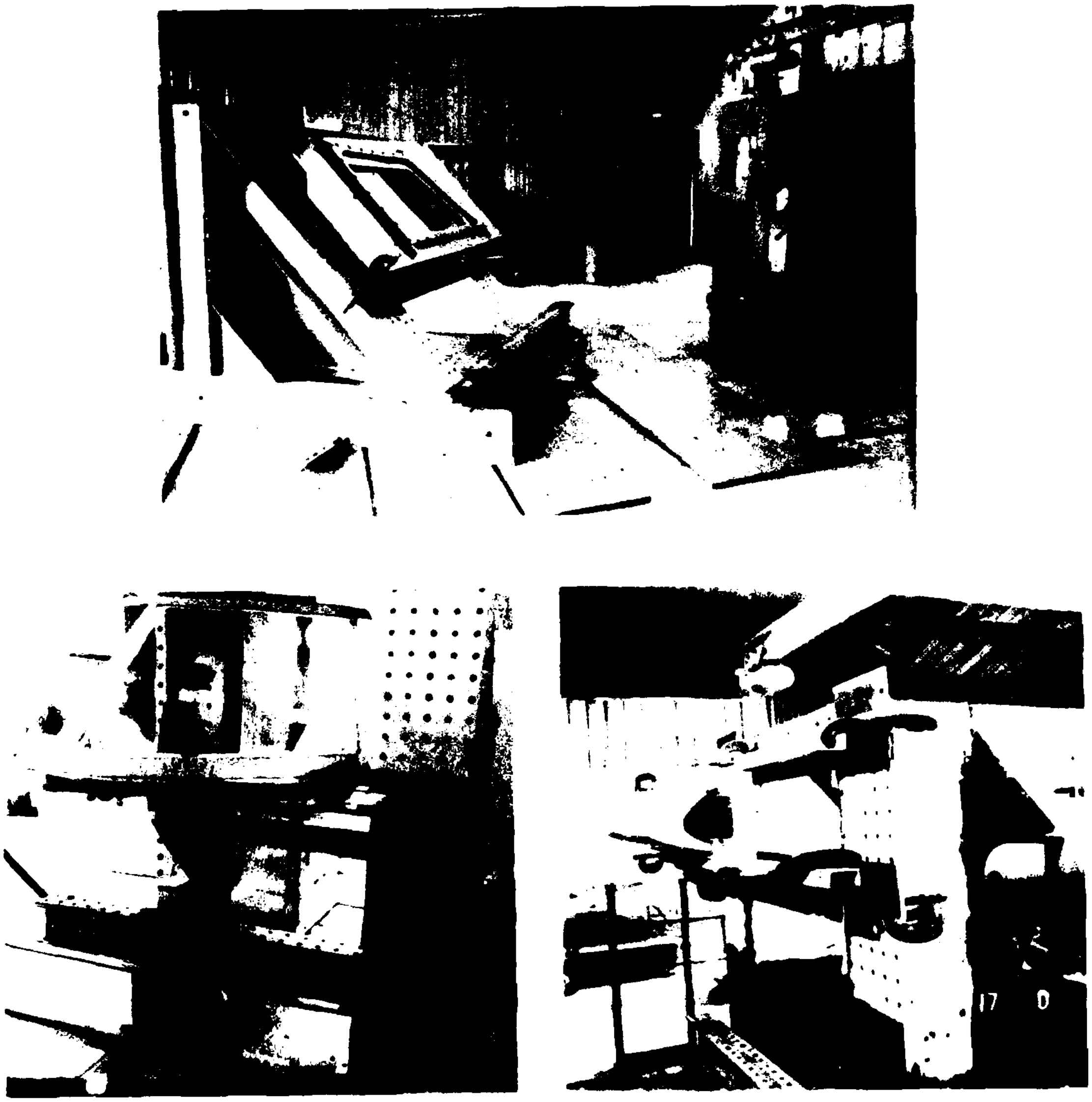


FIG. 8: TYPICAL TEST SET-UPS USING F.I.S. SUPPORT FRAMES

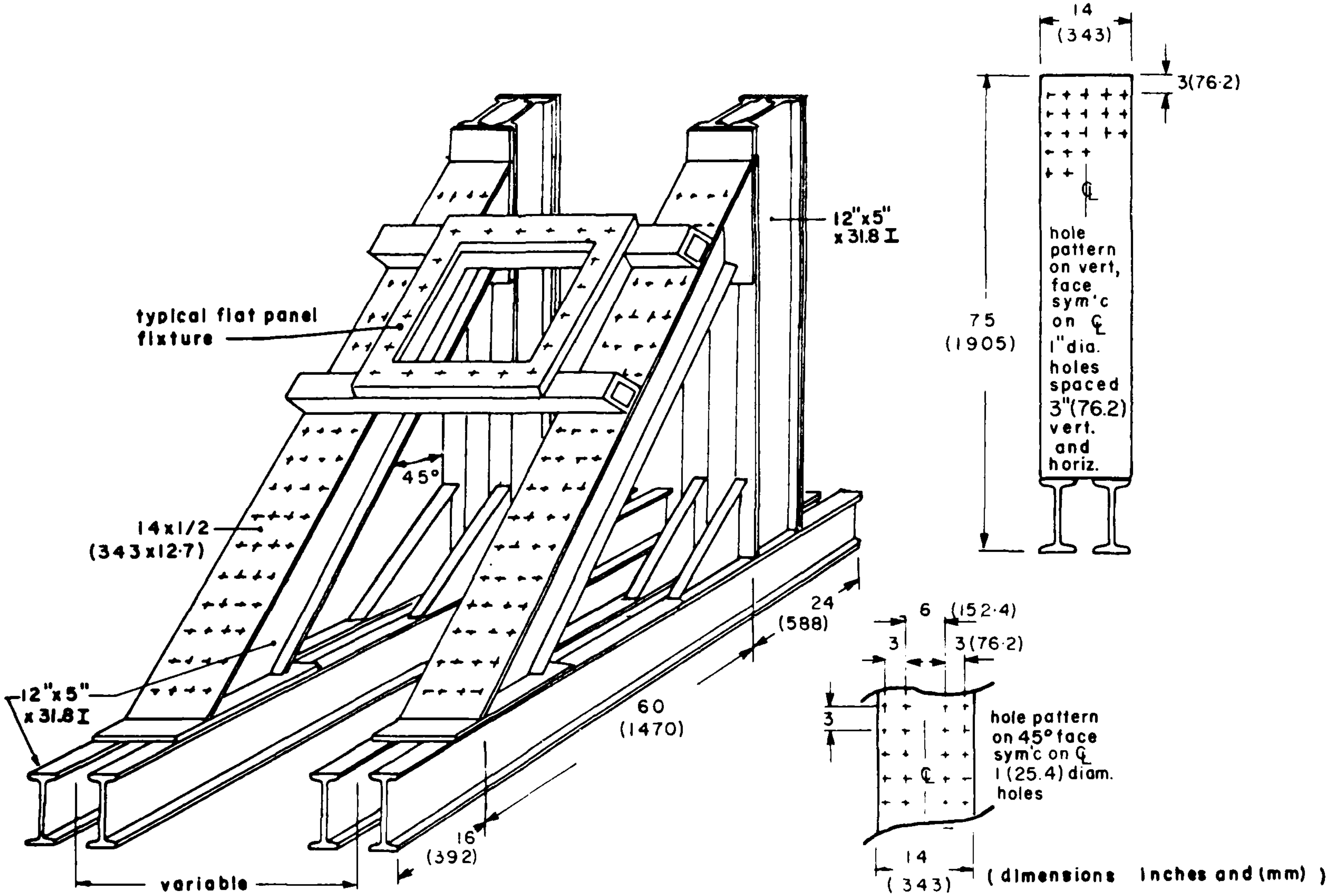


FIG. 9: SUPPORT FRAME

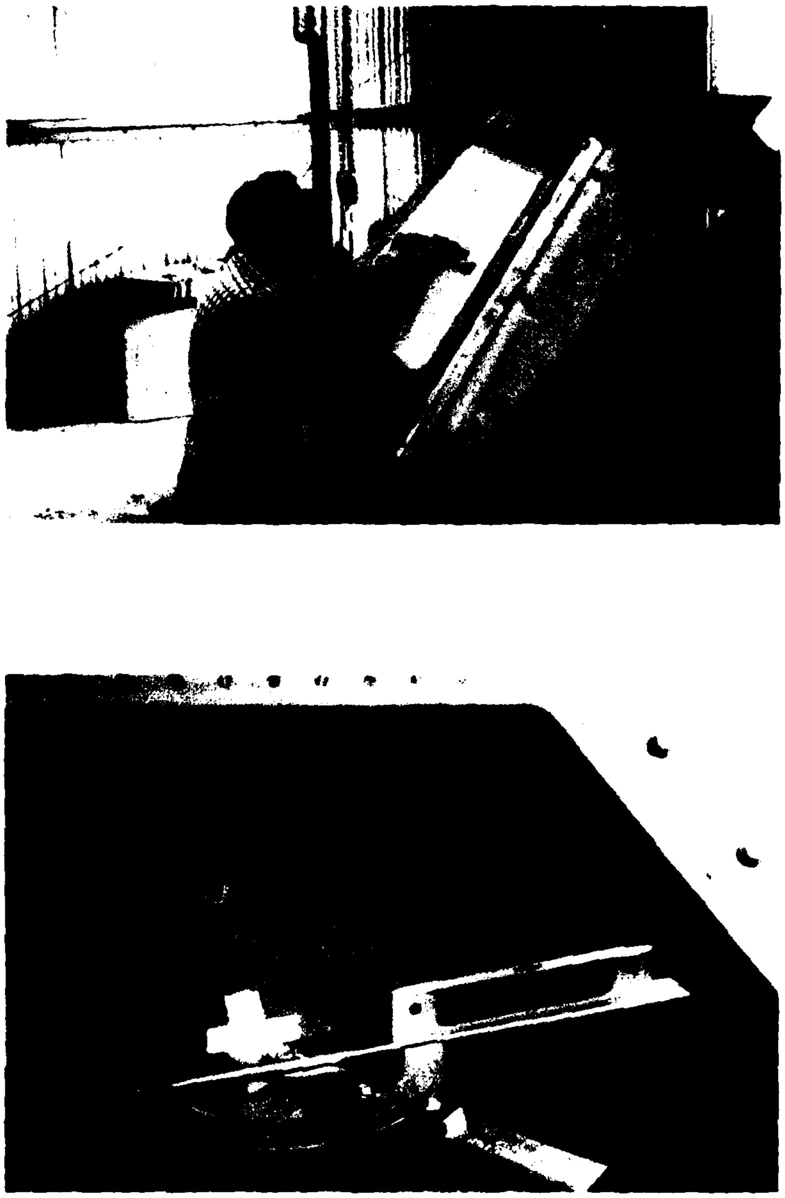


FIG. 10: SWEEPBACK ANGLE APPARATUS IN USE

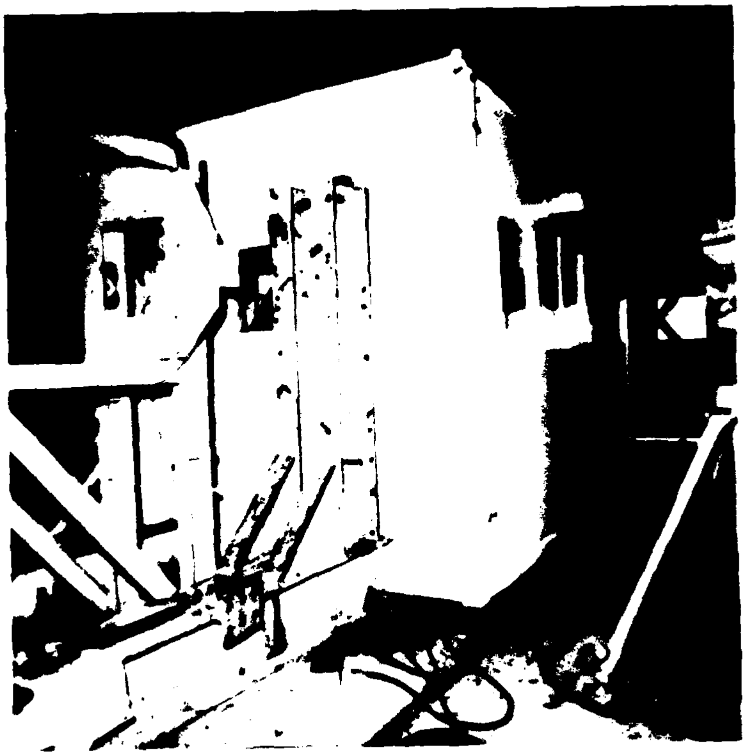


FIG. 11: TEMPERATURE CONDITIONING ENCLOSURE

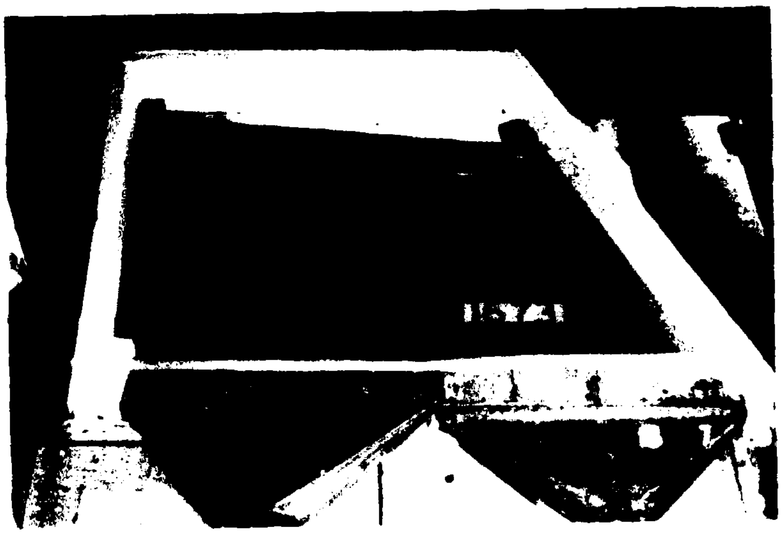


FIG. 12: STYROFOAM ENCLOSURE FOR HIGH OR LOW TEMPERATURE IMPACTS (COVER REMOVED)

FIG. 13: AIR-LIQUID NITROGEN MIXING BOX

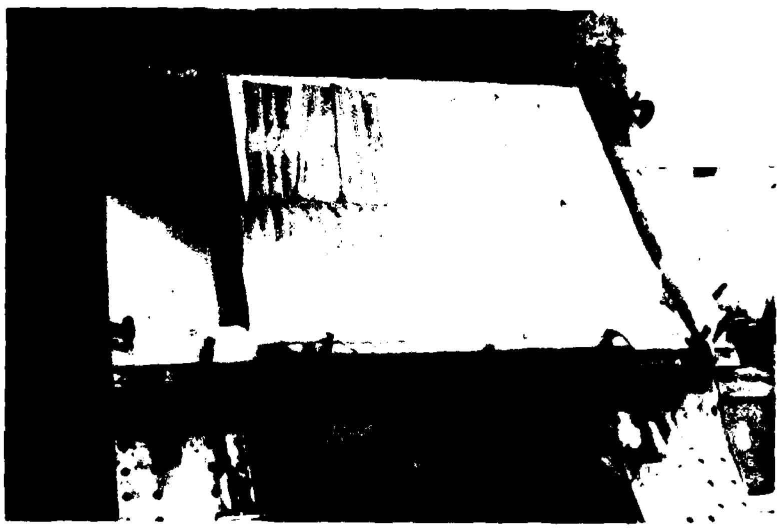


FIG. 14: WINDSHIELD HEATING WITH AN ELECTRIC BLANKET. INSULATED COVER SHOWN IN POSITION

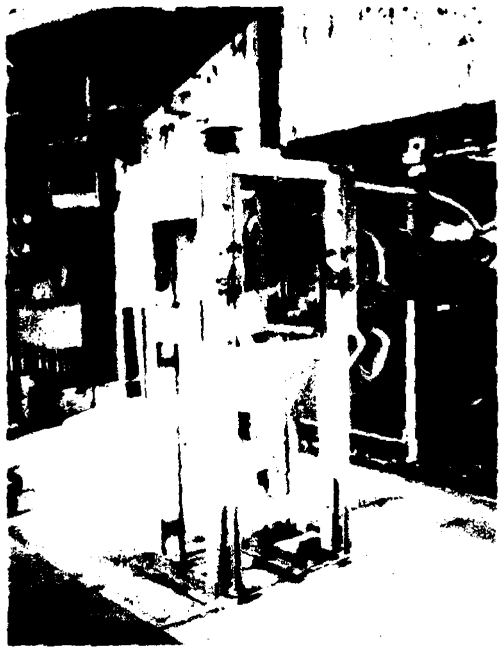
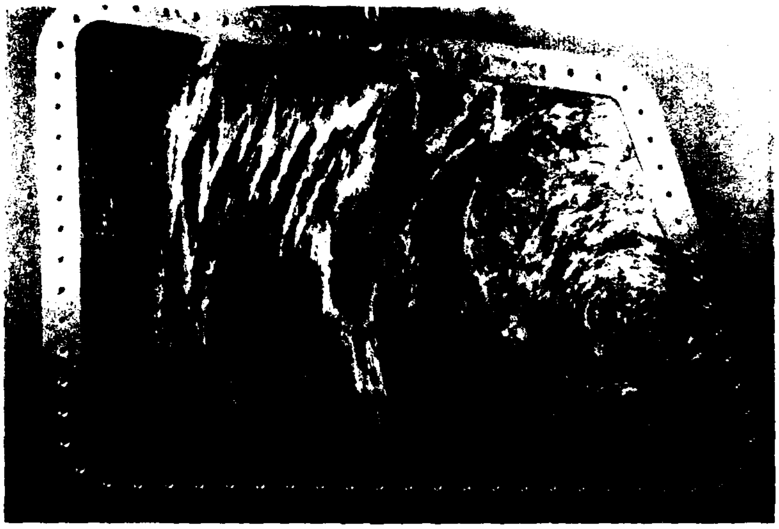


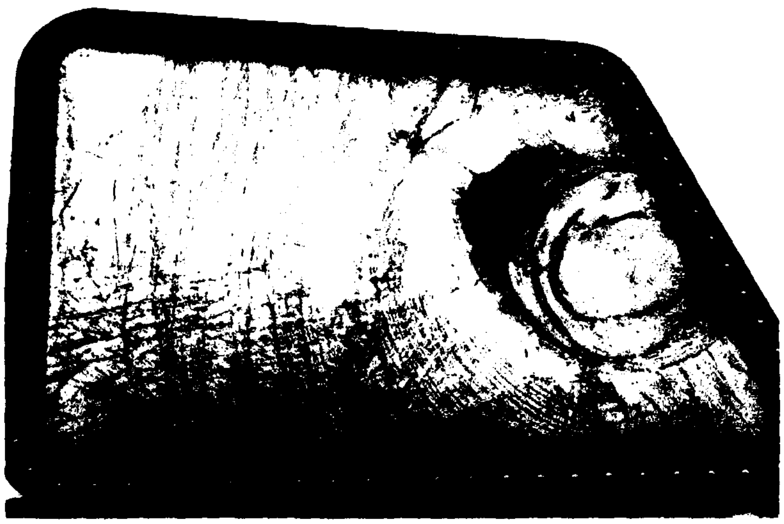
FIG. 15: TIMING FRAME

FIG. 16: DETAIL OF THE THREE "STOP" UNITS

FIG. 17: TIMING INTERVAL APPARATUS SHOWN IN POSITION



(a) WITH FLOOD LAMPS



(b) ON LIGHT TABLE

FIG. 18: DAMAGED WINDSHIELD PHOTOGRAPHY ENHANCED USING A LIGHT TABLE

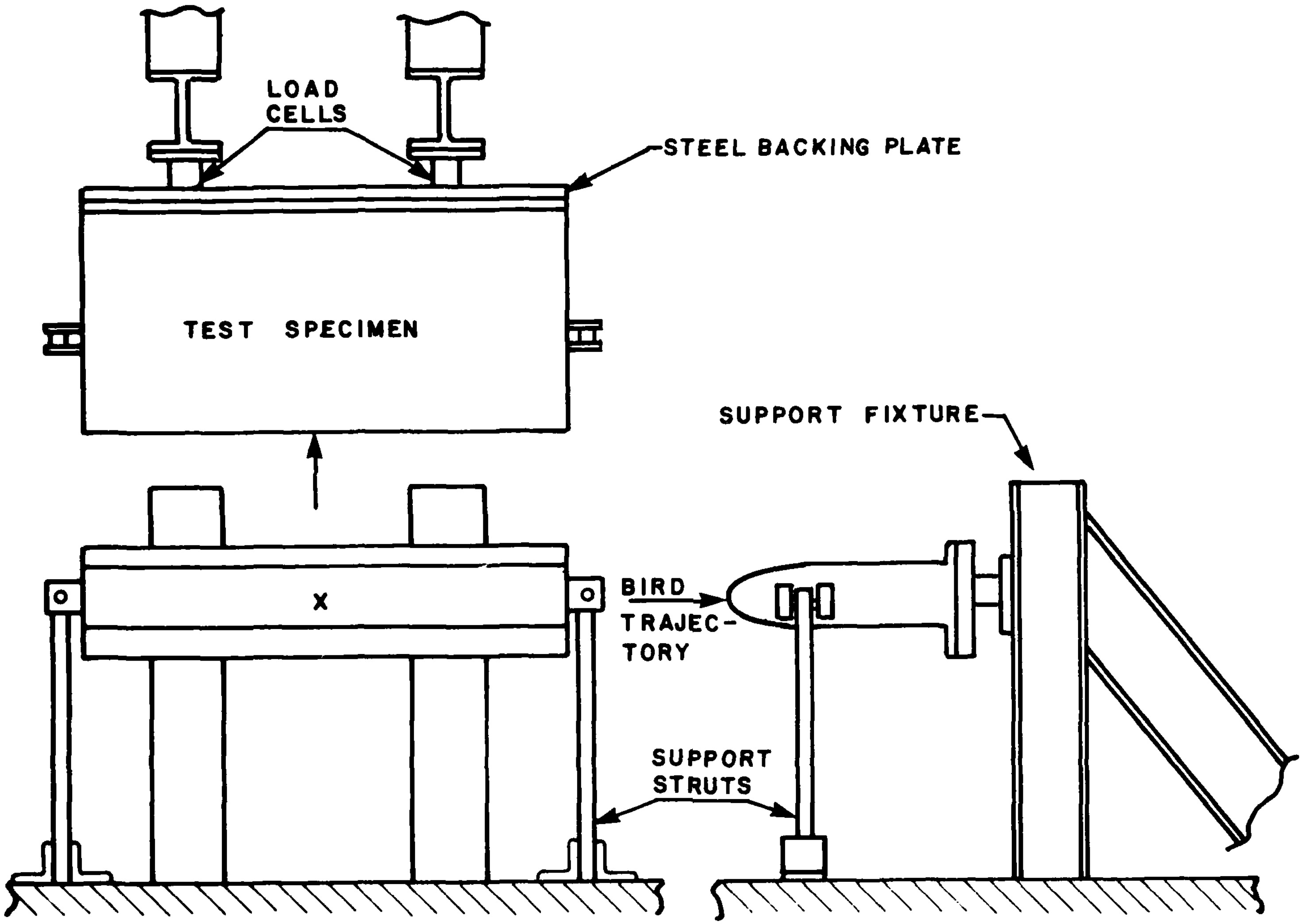


FIG. 19: A TEST SET-UP FOR MEASUREMENT OF PEAK FORCE AND FORCE VERSUS TIME HISTORY

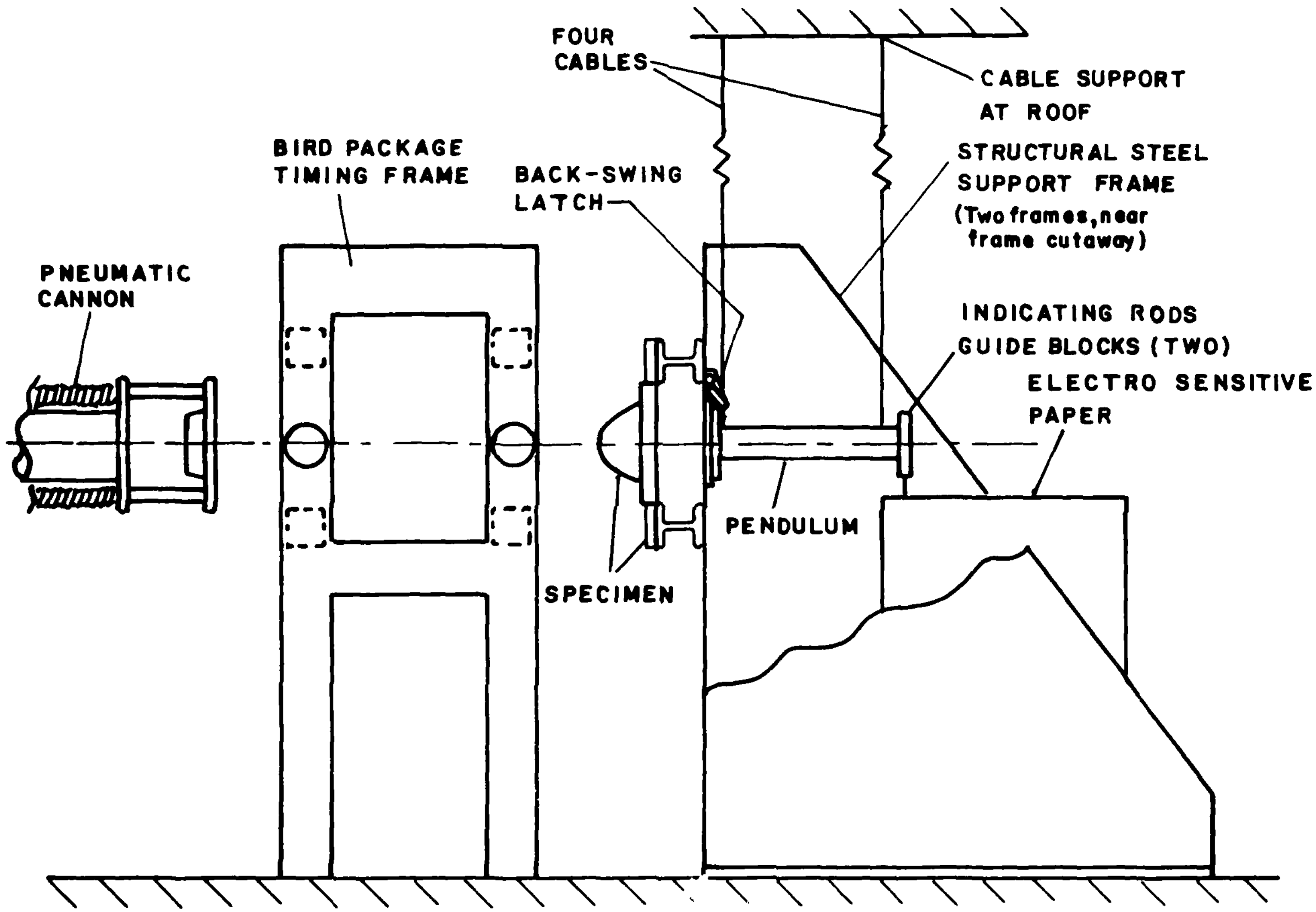


FIG. 20: SCHEMATIC OF BALLISTIC PENDULUM SET-UP

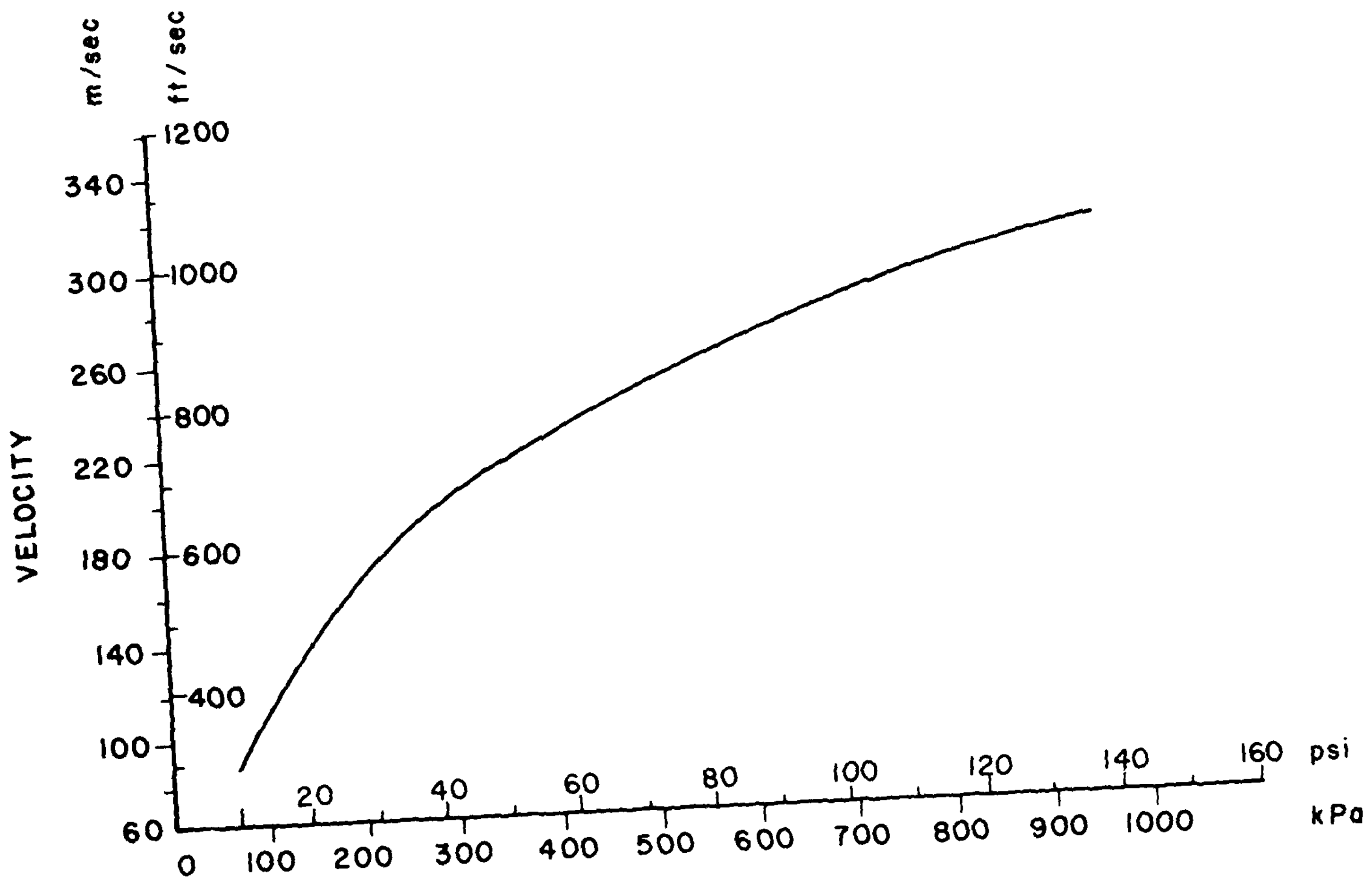


FIG. 21: PRESSURE VERSUS VELOCITY FOR A 1.8 kg (4 lb) BIRD

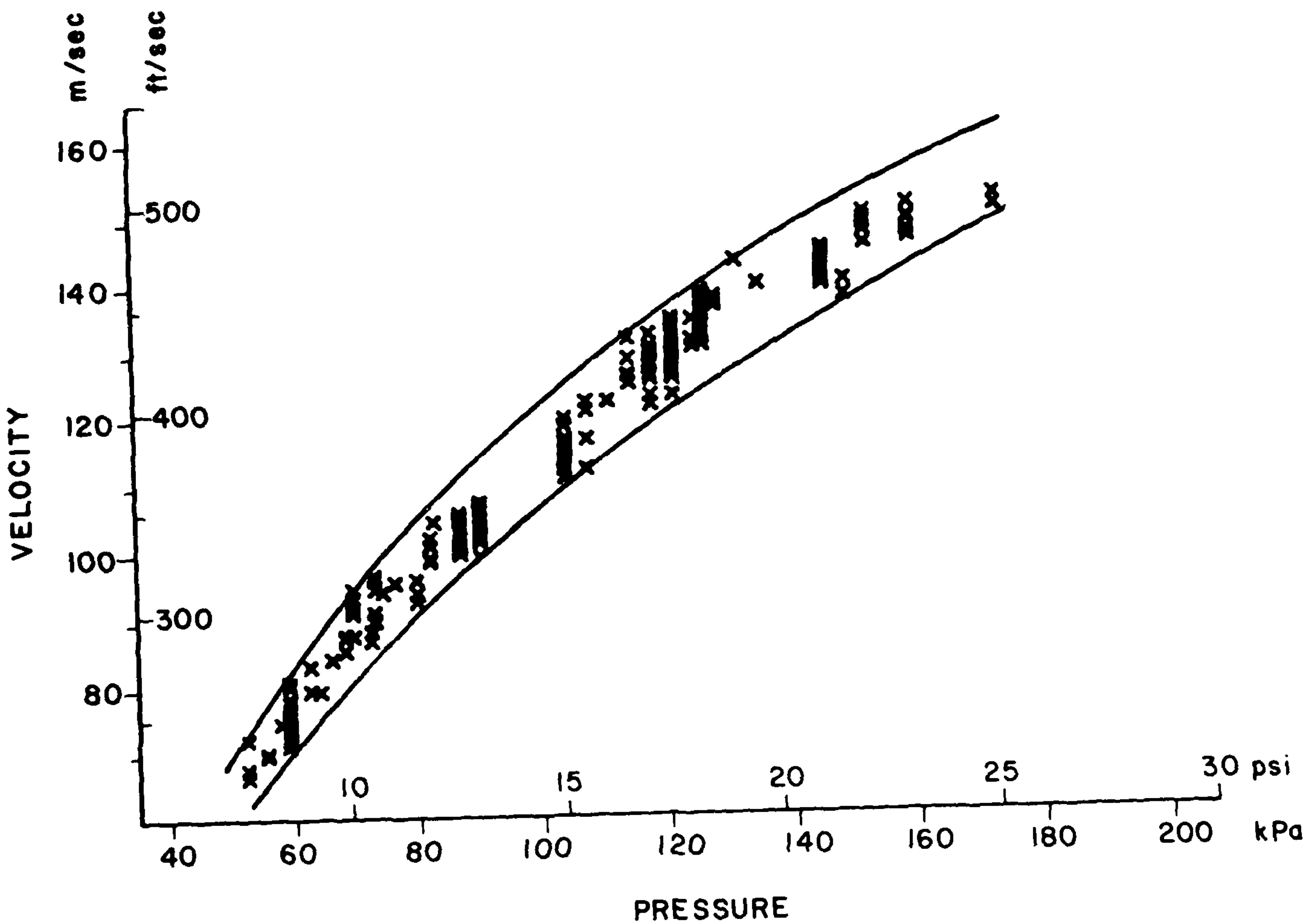


FIG. 22: PRESSURE VERSUS VELOCITY FOR A 1.8 kg (4 lb) BIRD

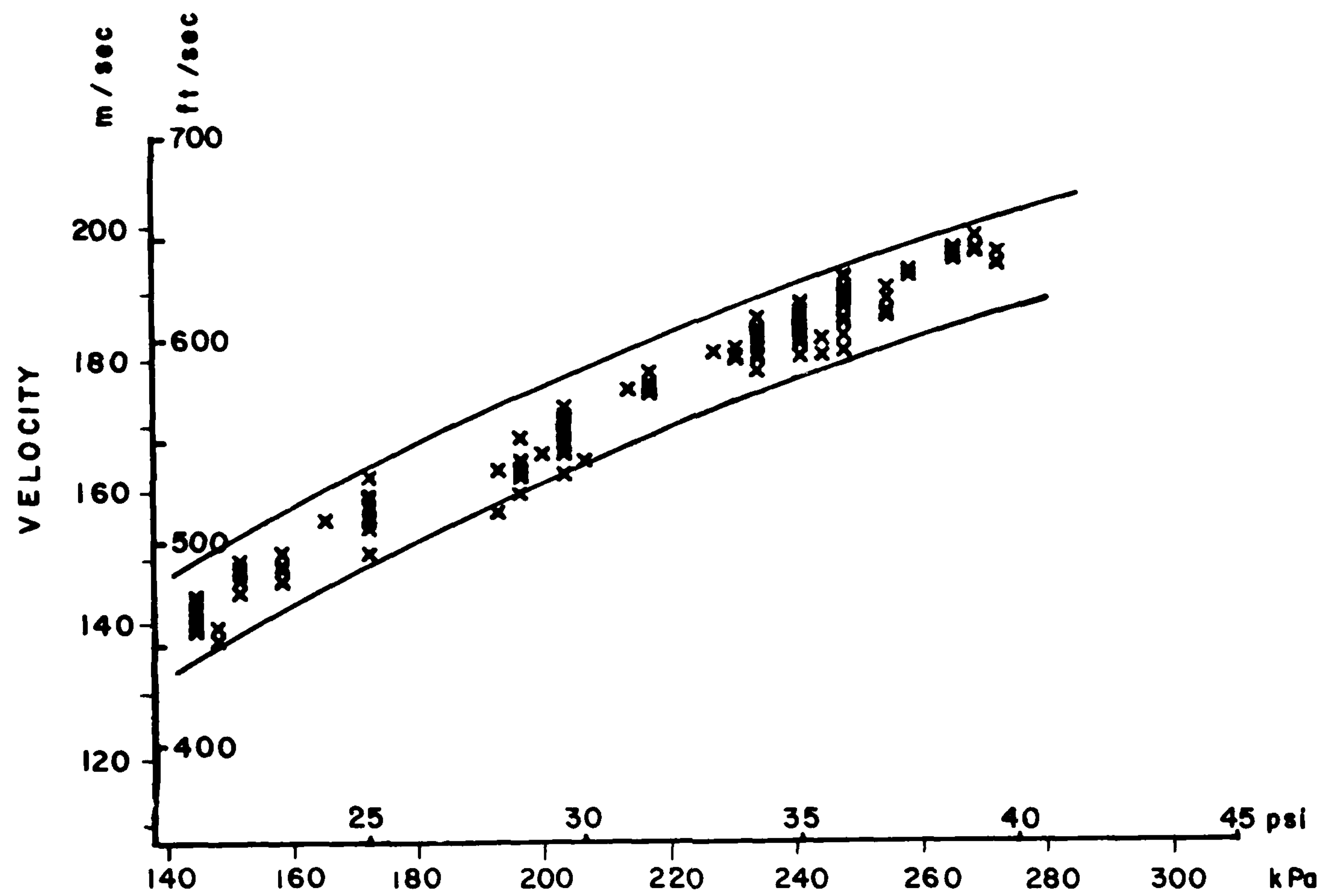


FIG. 23: PRESSURE VERSUS VELOCITY FOR A 1.8 kg (4 lb) BIRD

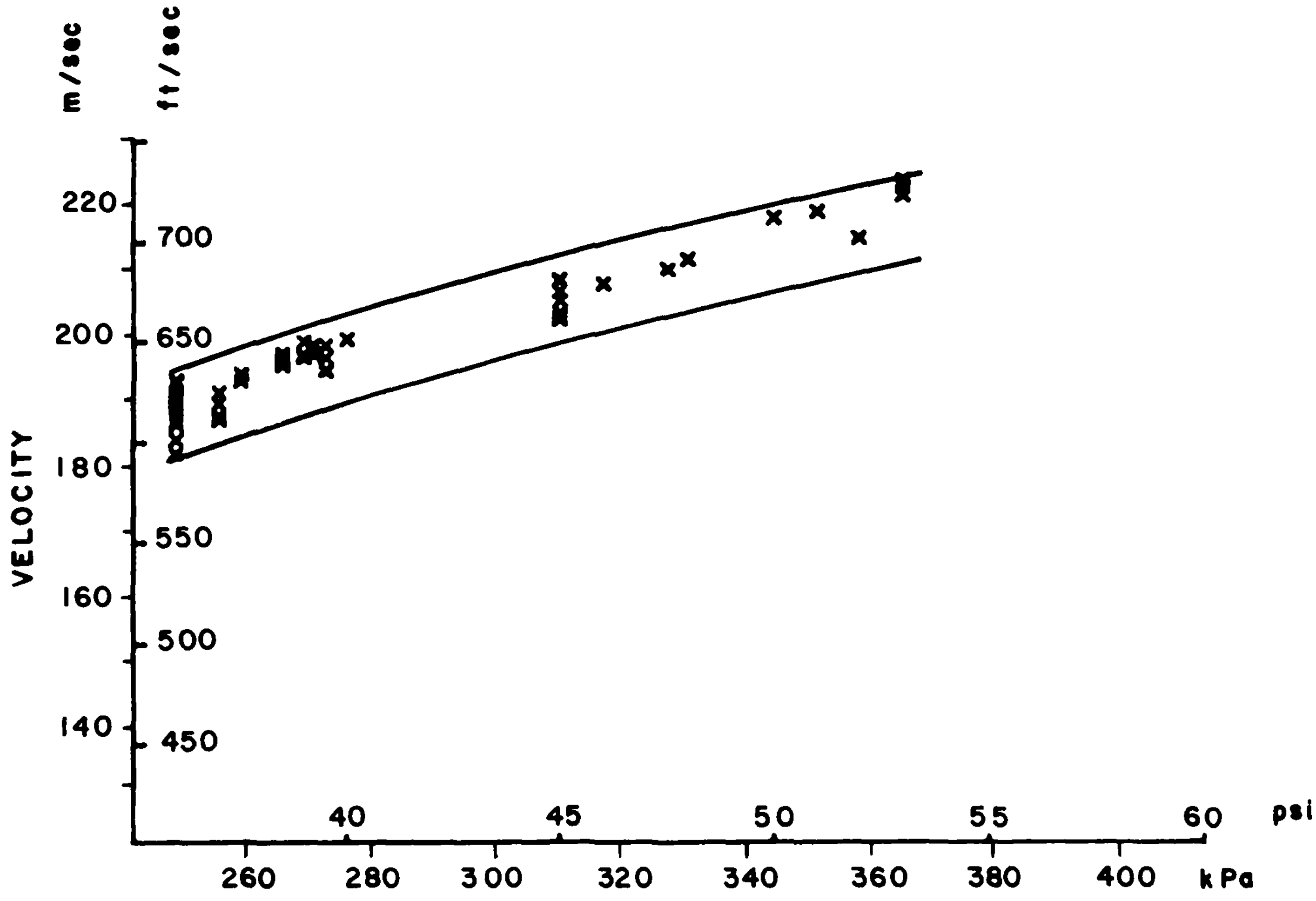


FIG. 24: PRESSURE VERSUS VELOCITY FOR A 1.8 kg (4 lb) BIRD

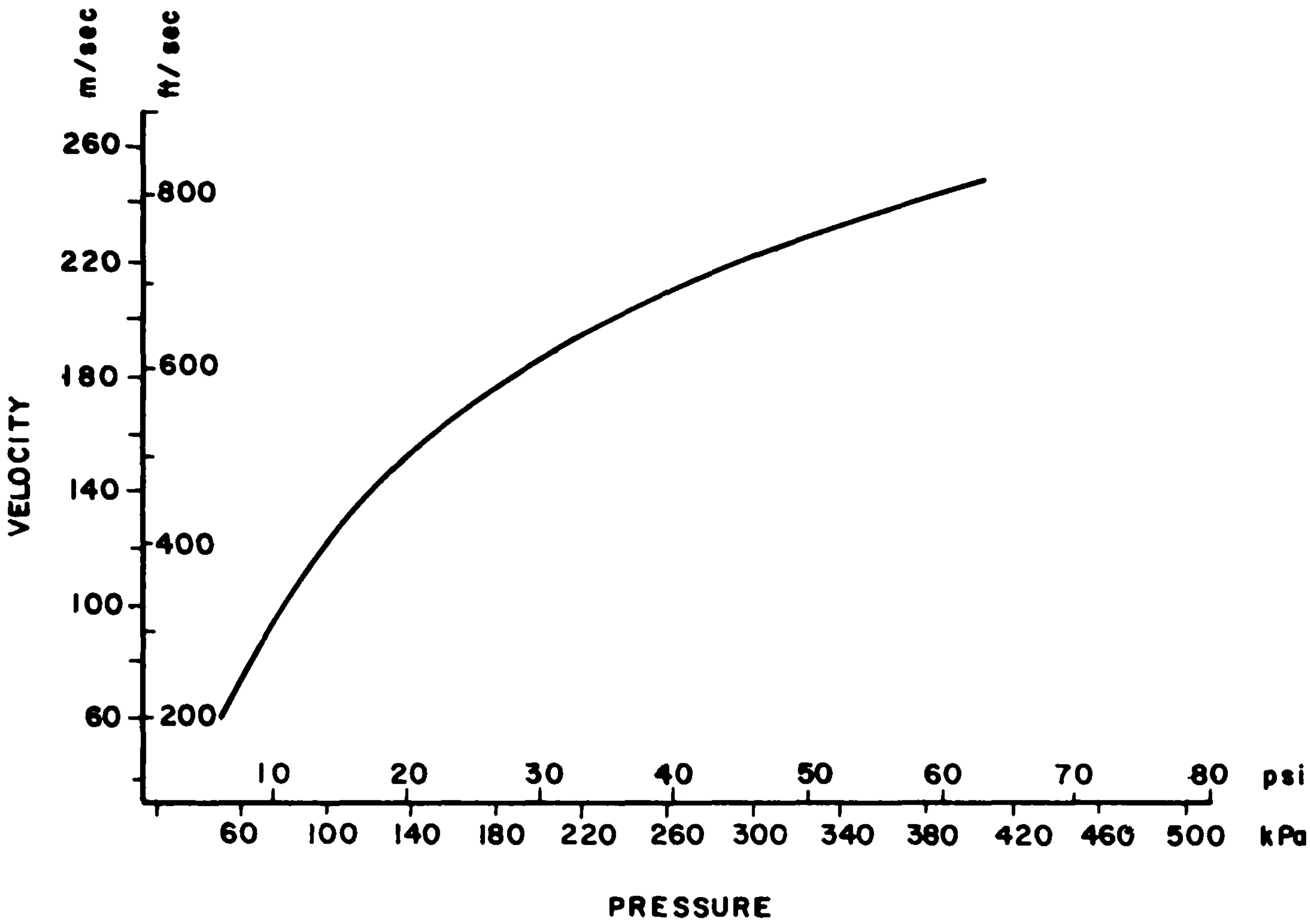


FIG. 25: PRESSURE VERSUS VELOCITY FOR A .9 kg (2 lb) BIRD

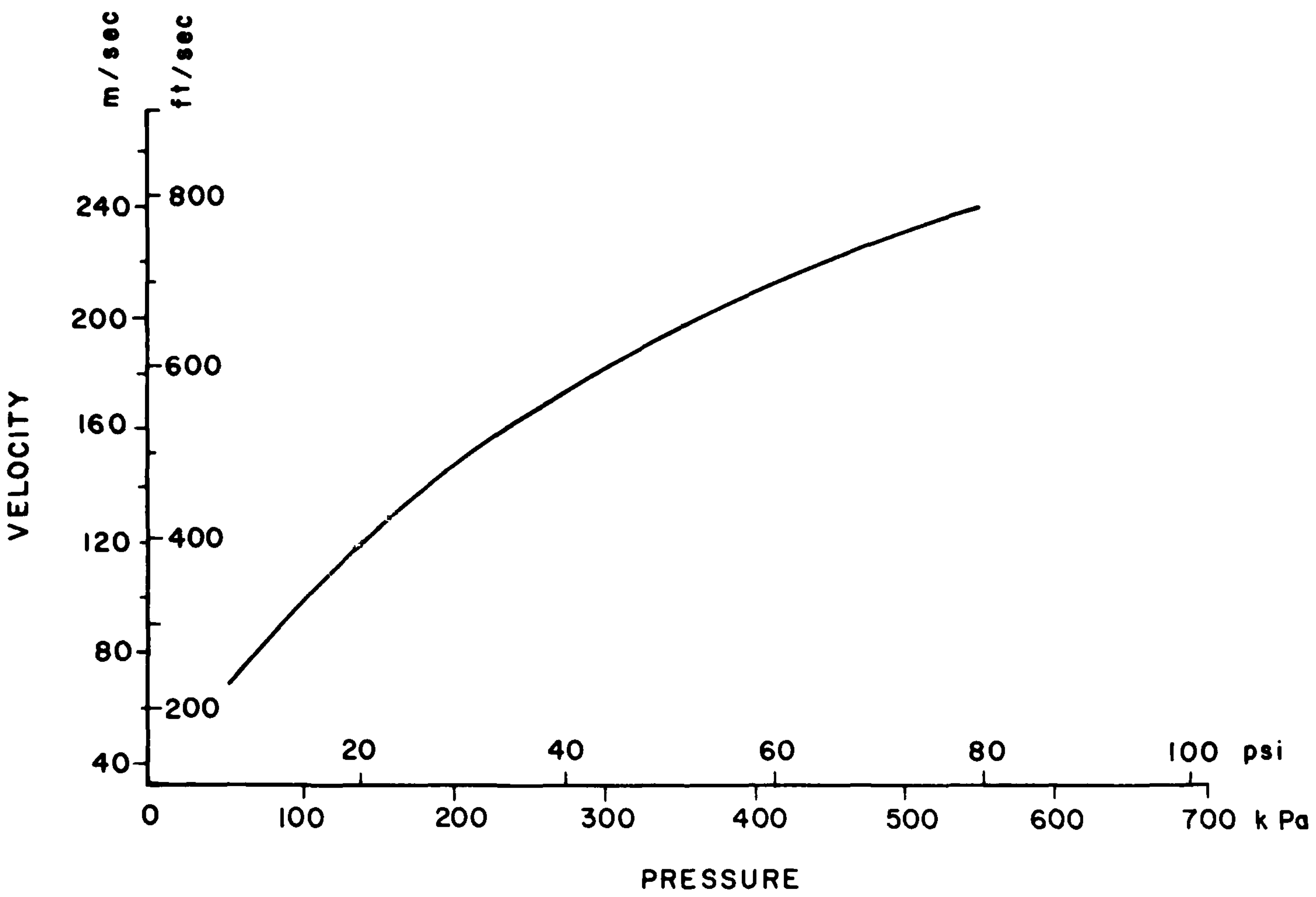


FIG. 26: PRESSURE VERSUS VELOCITY FOR A 3.6 kg (8 lb) BIRD

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Capabilities of the NRCC/NAE Flight Impact Simulator Facility

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2. Flight Impact Simulator Facility

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SUMMARY/SOMMAIRE

This report describes the NRCC/NAE Flight Impact Facility in which birdstrike tests on aircraft parts can be carried out. Technical information is given on the capabilities of the pneumatic cannon used to fire real bird carcasses against stationary targets, and on the auxiliary apparatus and instrumentation available at the Facility.

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